Penobscot River Modeling Report
Draft
April 2003

Paul Mitnik, P.E.
Bureau of Land and Water Quality
Division of Environmental Assessment

DEPLW-0582

Executive Summary

1. A study of the Penobscot River from Millinocket to Bucksport (103 miles) began in the summer of 1997 involving the DEP and a number of stakeholders such as the Penobscot Nation, Great Northern Paper, International Paper, USEPA, and the Lincoln Sanitary District
2. Data was collected in the summers of 1997 and 2001 to calibrate and verify a water quality model. The lack of runoff prior to the survey, presence of low flow conditions (about 5 year low flow and 97% flow duration), and utilization of good QA/QC measures resulted in excellent quality data to calibrate the water quality model.
3. Non-attainment of class B dissolved oxygen criteria was observed at only one location in 1997, but at ten of fourteen locations sampled in 2001. Chlorophyll a results exceeded the algae bloom threshold (8 ug/l) at only one location in 1997 but five of the fourteen locations sampled in 2001. For detailed descriptions of the data, one should consult the Penobscot River Data Report (MDEP, April 1998 and May 2002).
4. MDEP's version of the EPA supported model, QUAL2EU, (QUAL2MDEP) was used to model the Penobscot River and estuary. Some of the important changes to QUAL2EU include the addition of a periphyton module and benthic BOD component, an enhanced dissolved oxygen saturation calculation that adds salinity as a dependent variable, and alteration to phosphorus output units to the nearest 0.1 ppb.
5. The model was calibrated and verified with comparisons of the model output of salinity, BOD, phosphorus, nitrogen, chlorophyll-a and dissolved oxygen to the data observed in the summers of 1997 and 2001. Good comparisons resulted. All values assigned as parameter rate inputs were within recommended ranges in the literature. The model is considered to be a good predictive tool for estimating river dissolved oxygen and algae levels.
6. The model run at worse case conditions of 7-day-10-year low flow (7Q10), high water temperatures, and point sources at licensed loads predicts that minimum dissolved oxygen criteria (7 ppm) will not be met in approximately 51 class B river miles or about ½ of the 103 miles modeled. In addition algae blooms are projected to occur in about 25 miles or about ¼ of the 103 miles.
7. Point sources account for about 74% and 94% of the total BOD and phosphorus loads, respectively, that enter the Penobscot River. Paper mills are about 80% and 70% of the total point source loads for BOD and phosphorus, respectively.
8. A component analysis was undertaken at three strategic points on the river to determine the causes of dissolved oxygen depletion. The following causes were determined to be the most significant
   <u>Above Rockabema Dam</u> – Sediment Oxygen Demand (37%) and Background (37%)
   <u>Passadumkeag - Greenbush</u> – Point Source Nutrients (45%) Sediment Oxygen Demand (35%)
   <u>Orrington</u> – Point Source BOD (43%) and Sediment Oxygen Demand (37%)
9. Point source reductions of 60% for BOD5 from current licensed amounts (slightly higher than actual performance levels) and reductions of 40% of total phosphorus from actual levels are needed to achieve dissolved oxygen criteria on the entire 103

mile segment. Algae blooms would also be eliminated with these reductions

10. There are many methods that could be used to allocate point source reductions. The following is offered as a starting point for discussions on how to implement point source reductions in waste discharge licenses.

Table 14 Point Source BOD5 and Phosphorus Allocation

Municipal Discharges

Point Source Discharge	Weekly Average / Daily Maximum BOD5 (PPD)		Total Phosphorus (PPD)	
	Allocate by current discharge	Allocate by equal concentration	Allocate by current discharge	Allocate by equal concentration
Millinocket	180 / 200	210 / 230	28	24
Lincoln	50 / 55	90 / 100	12	10
Old Town	400 / 480	220 / 250	36	26
Orono	100 / 110	180 / 200	18	21
Veazie	16 / 18	28 / 31	3	3
Bangor	900 / 1000	1470 / 1630	212	169
Brewer	230 / 250	620 / 690	15	71
Winterport	Primary Plant		No Restriction	
Bucksport	Primary Plant		No Restriction	

Paper Mills

Point Source Discharge	Weekly Average / Daily Maximum BOD5 (PPD)		Total Phosphorus (PPD)	
	Allocate by current discharge	Allocate by equal concentration	Allocate by equal % Reduction	Allocate by equal concentration
GNP West	8200 / 10800	8700 / 11500	96	87
GNP East	1450 / 2600	1800 / 3200	97	88
E Paper Lincoln	5000 / 6800	2700 / 3700	30	45
G Pacif Old Town	3600 / 5100	4000 / 5600	63	66
IPCo Bucksport	7100 / 10000*	No Restriction		

* Current licensed levels

Table of Contents

page
Introduction……………………………………………………………………………1
Summary of 1997 and 2001 Data………………………………………………...1
Water Quality Model ……………………………………………………………….8
Model Transport……………………………………………………………………….10
Chemical Calibration of Water Quality Model……………………………………..10
Model Prediction Runs at 10-Year Low Flow………………………………………30
Sensitivity Analysis………………………………………………………………… 40
Component Analysis…………………………………………………………….. 40
Investigation of Pollutant Abatement ……………………………………………… 47

Figures

1. Point Source Pollutant Discharge Comparisons 1997 Vs 2001…………………..5
2. Comparisons of Temperature 1997 Vs 2001……………………………………..6
3. Comparisons of Dissolved Oxygen 1997 Vs 2001 ………………………………7
4. Penobscot River Model Setup…………………………………………………….9
4a. Ln Salinity Vs River Mile……………………………………………………….12
5. Dispersion Calibration Penobscot Estuary………………………………………..14
6. Sample Station Location Vs River Mile…………………………………………..18
7. Ultimate BOD Calibration ……………………………………………………….20
8. Chlorophyll a Calibration…………………………………………………………21
9. Total Phosphorus Calibration……………………………………………………..22
10. Orthophosphorus Calibration…………………………………………………….23
11. Total Nitrogen Calibration………………………………………………………24
12. Diurnal Dissolved oxygen Adjustment Used in Model…………………………25
13. Sediment Oxygen Demand Measured Vs Model ………………………………27
14. Daily Average Dissolved Oxygen Calibration …………………………………28
15. Diurnal Dissolved Oxygen Calibration…………………………………………29
16. Determination of 10-Year Low Flows………………………………………….31
17. Determination of Design River Temperature…………………………………...32
18. Model Predicted Daily Minimum Dissolved Oxygen ………………………….36
Point Sources at Licensed and Zero Discharge
19. Model Predicted Monthly Average Dissolved Oxygen…………………………37
Point Sources at License
20. Licensed Vs Actual BOD5 of Point Sources……………………………………38
21. Model Predicted Daily Minimum Dissolved Oxygen…………………………...39
Point Sources at Licensed and Actual Discharge
22. Summary of Sensitivity Analysis ………………………………………………41
23. Pollutant Sources tp Penobscot River as Pie Chart Comparisons ………………43
24. Licensed Point Source BOD5 – Pie Chart Percentage Comparison…………….44

25. Total Point Source Phosphorus Discharged During Intensive Surveys…………45
Pie Chart Percentage Comparison
26. Components of Dissolved Oxygen Depletion – Pie Chart Comparison…………46.
27. Various Point Source Allocations at 7Q10 Flow………………………………..50
28. Licensed BOD5 Vs Equal BOD5 Concentration Allocation……………………53-55

Tables

1. Major Point Sources on the Penobscot……………………………………….…2
2. Dams on the Penobscot…………………………………………………………2
3. Penobscot River Model Hydraulic Coefficients………………………………….11
4. Dispersion Calculations………………………………………………………..12
5. Flow Balance for Penobscot River ………………………………………………13
6. Environmental Parameter Rates Used in Model – Variable by Reach……………16
7. Environmental Constants and Parameter Rates Used in Model…………………...17
Constant by Reach
8. Dilution of Riverine Point Source Discharges……………………………………..30
9. Point Load Inputs at 7Q10 and 30Q10 Flow……………………………………….34
10. Point Load Nutrient Concentration Inputs at 7Q10……………………………….34
11. Model Input for WWTP Performance Run………………………………………..40
12. Summary of Model Prediction Runs – Inputs and Results……………………… 48
13. Summary of Point Source Loads Used in Model Prediction Runs………………...49
14. Point Source BOD5 and Phosphorus Allocation…………………………………..52

Introduction

The Penobscot River Basin is the largest river basin lying entirely within the state of Maine. It has a drainage area of 8592 square miles at its mouth. The river segment of interest on the Penobscot River begins in Millinocket below Ferguson Lake as the West Branch, where after 10 miles it joins with the East Branch. It then flows an additional 69 miles before reaching head of tide at the Veazie dam, and then over 24 additional miles of tidal waters to Bucksport. In this 103-mile segment, there are 15 point source discharges, 11 dams, and 9 tributaries that have a drainage area of over 100 square miles. A list of dams and point sources are illustrated in tables 1 and 2.

The Penobscot River model is a result of an ongoing effort by DEP and stakeholders. A model for this 103 mile segment was first set up by DEP in 1991 (Penobscot River Basin Waste Load Allocation, Jan 1991). This report revealed that the river was at its limit for receiving point source discharges while still maintaining water quality standards.

The effort undertaken from 1997 to current updates the model to modern conditions. Two separate Penobscot River Data Reports (April 1998, and May 2002, MDEP) discuss the data that were collected by DEP and a number of stakeholders such as the Penobscot Nation, Great Northern Paper, International Paper, USEPA, and the Lincoln Sanitary in the summers of 1997 and 2001. The 1997 data were collected to calibrate the water quality model. The Penobscot River Modeling Report (June 2000) discusses the modeling effort derived from the calibration of the model to the 1997 data. This modeling effort revealed that the Penobscot River was beginning to develop some water quality non-attainment issues (lower than required dissolved oxygen and algae blooms). An additional data set for model verification was recommended in the summer of 2001 to more accurately assess the situation and consider cleanup alternatives. This report represents the final recommendations for the Penobscot River based upon a completed modeling effort.

Summary of 1997 and 2001 Data

The overall quality of both the 1997 and 2001 data are considered excellent due to good QC measures utilized throughout the sampling effort that involved such practices as cross checking of dissolved oxygen meters and duplicate sampling. The three-day intensive surveys were undertaken on August 5,6, and 7 of 1997 and August 7,8,and 9 of 2001 and were specifically for calibration and verification of the water quality model. It is desirable to collect the model calibration data sets under conditions of low flow and high water temperature. This represents conditions of worse case when river dissolved oxygen levels are most likely to be the lowest. At lower river flow, the dilution of waste loads is reduced resulting in river pollutant concentrations of higher strength. At high water temperatures, dissolved oxygen saturation decreases and the biological activity increases resulting in a greater amount of oxygen demand in the water column as BOD (biochemical oxygen demand) and greater amount of oxygen demand from bottom sediments (SOD). Thus water column dissolved oxygen depletion is maximized under these conditions.

A goal of sampling at less than 4400 cfs as measured at the USGS gage in West Enfield (90% flow duration) was used as a target flow for the three-day intensive survey. This goal was met in both intensive surveys. The three-day average flow was 3620 cfs in 1997 and 3400 cfs in 2001. Both data sets represent about a 97 % flow duration or about a 5-year low flow event.

Another preferable sampling condition is having no runoff during and prior to the survey. Runoff is undesirable due to the difficulty of quantifying it as input to the model. One of the water quality model's underlying assumptions requires steady state conditions. This would not be met if significant runoff occurred during or two to three days prior to the sampling event. There was no runoff three weeks prior to August 5,6,7 of 1997 and no runoff ten days prior to August 7,8,and 9 of 2001.

The upper 22 miles of the study reach from Millinocket to the confluence of the Mattawamkeag River (River Miles or RM 83 – 61) are classified C requiring minimum dissolved oxygen to not be less than 5 ppm and 60 % of saturation. Six locations were sampled in this class C reach for dissolved oxygen and temperature. The next 67 miles from the Mattawamkeag River to Reeds Brook in Hampden (RM 61 to –6) are classified B waters with the exception of 1 mile directly above the Enfield dam (RM 38 to 37) which is classified C. Fourteen locations were sampled for dissolved oxygen and temperature in the class B reach and one location in the class C reach above the Enfield dam. Class B waters require that a minimum dissolved oxygen level of 7 ppm and 75% of saturation be maintained at all times. The final 22 miles of the study reach are tidal waters and are classified SC. Nine locations were sampled for dissolved oxygen and temperature in the class SC reach. Class SC requires that minimum dissolved oxygen of 70% of saturation be maintained at all times.

The 1997 data indicated that minimum statutory dissolved oxygen criteria were met and often greatly exceeded at all locations, except North Lincoln, where minor non-attainment of class B dissolved oxygen criteria sometimes occurred. Of significance, however was the fact that point source discharges were at only 10% of their licensed permitted BOD5 (five-day biochemical oxygen demand[1]) limits. Hence the potential for lower dissolved oxygen levels than measured is possible, and worse case levels must be determined by the model. The 2001 data indicated that dissolved oxygen criteria were not met in 10 of the 14 locations sampled in class B waters. About 50 river miles are estimated to currently not attain class B minimum dissolved oxygen criteria. The BOD5 discharged by point sources was about 17% of licensed amounts during the 2001 sampling event. In class C and class SC waters, the 2001 data indicate that dissolved oxygen criteria were maintained.

A chlorophyll-a[2] level of 8 ug/l is used as a threshold level indicating the occurrence of an algae bloom. When chlorophyll a levels approach this threshold, the water may begin

[1] Biochemical oxygen demand (BOD) is a laboratory test estimating the amount of oxygen demanding substances in water samples. The oxygen depletion of a water sample is measured over a time increment. The five-day test or BOD5 is typically used to measure BOD in effluent samples from wastewater treatment plants. Hence, this test measures the potential of discharges to deplete oxygen within a river.
[2] The chlorophyll-a test is used as an indicator to quantify the amount of phytoplankton or floating algae within a water sample.

to appear green tainted from plankton that are floating in the water. The plankton may also be visible within the water column. Only one location exceeded 8 ug/l in 1997; the average three-day chlorophyll a was 9 ug/l at the Weldon dam. Other locations at Dolby dam and three locations within the estuary had levels approaching 8 ug/l. The data and modeling reports indicated that a eutrophication problem on the Penobscot River could be forthcoming.

The 2001 data indicates a further deterioration in eutrophic state in the Penobscot. Chlorophyll a levels exceeded the threshold of 8 ug/l at five of the fourteen locations sampled; including above Dolby, Rockabema, and Weldon dams on the West Branch and upper Penobscot and Orrington center and South Orrington in the estuary.

Both the chlorophyll-a levels and dissolved oxygen readings indicate deterioration in water quality when compared to the 1997 data. Conditions of river flow, water temperature and waste load inputs were examined as an initial attempt to explain the lower water quality experienced in 2001. River flow was not significantly different in both data sets (3620 Vs 3400 cfs at Enfield in 1997 and 2001, respectively).

A comparison of point source inputs (Figure 1) indicates that point sources discharged higher amounts of pollutants in 2001 when compared to 1997. Point sources collectively were discharging 739 ppd. of total phosphorus in 1997 and 1250 ppd. of total phosphorus in 2001 representing an increase of 69%. Point sources collectively were discharging 30,600 ppd. of total ultimate BOD[3] in 1997, and 45,300 ppd. of total ultimate BOD in 2001 representing an increase of 48%.

A comparison of water temperature (figure 2) indicates that levels in 2001 were typically 3 to 4 ^{o}C higher than 1997. As explained earlier in the text, higher water temperatures generally result in lower dissolved oxygen. Higher water temperatures also result in conditions more favorable for algae growth.

The higher water temperatures, and higher inputs of BOD and phosphorus collectively result in lower dissolved oxygen at virtually all locations in 2001 than 1997 (figure 3). The higher levels of algae can be explained by the higher phosphorus inputs and higher water temperatures. Algae creates a diurnal cycle of the lowest dissolved oxygen in the early morning after extended respiration and the highest dissolved oxygen in mid to late afternoon during extended photosynthesis and respiration. A larger range (diurnal dissolved oxygen) of the AM and PM dissolved oxygen readings usually indicates more

[3] The ultimate BOD test (UBOD) involves observing oxygen depletion in a water sample in a laboratory over a period of 60 days or more until nearly all of the oxygen demand is utilized. It is a more accurate representation of oxygen demand than the five-day test, and is typically used in modeling studies. The five-day test was originally thought to capture about 60% of the total UBOD, but Maine studies have shown that the five-day test typically captures much less than 60% of the UBOD. Total ultimate BOD (TBODu) is the sum of both the carbonaceous and nitrogenous components of BOD.

algal activity. The larger diurnal dissolved oxygen in the 2001 data is evident when compared to the 1997 data (figure 3).

Water Quality Model

The EPA supported model, QUAL2EU was used in the analysis of the Penobscot. Steady state flows and load inputs are required and major transport mechanisms of advection and dispersion must be one-dimensional. The lack of runoff that was previously discussed satisfies the steady state condition. The uniformity of the dissolved oxygen and temperature readings in the vertical profiles indicates that the Penobscot is a well-mixed system and hence one-dimensional flow occurs. The Penobscot River should be well suited to this model.

Many changes were recently incorporated into MDEP's version of QUAL2EU or more appropriately named QUAL2MDEP. The changes are as follows:

1. Addition of a periphyton module with links to the nutrient and dissolved oxygen modules. A major shortcoming of QUAL2EU is bottom attached algae can not be directly modeled. The majority of impacts now experienced in rivers involve low early morning dissolved oxygen from bottom attached algae. The QUAL2MDEP model can now be used to model bottom attached algae and the resulting diurnal dissolved oxygen swings.
2. Addition of a benthal BOD component. QUAL2EU models the direct oxygen demand from bottom sediments, but the sediment may also add BOD to the water column. This is particularly significant in long river systems like the Penobscot with long travel times to accurately model non-point source impacts. This was identified as a deficiency in QUAL2EU (see page 6, Penobscot Modeling Report, June 2000).
3. Enhancement of the dissolved oxygen saturation calculation. QUAL2EU calculates dissolved oxygen saturation as a function of temperature. This results in unnecessary error in marine situations, since salinity also affects dissolved oxygen saturation. Salinity is now included into the dissolved oxygen saturation calculation.
4. Alteration to phosphorus output units. QUAL2EU's output for organic phosphorus and dissolved phosphorus is rounded off to the nearest 10 ppb. This has been changed in QUAL2MDEP so the output for phosphorus components are now rounded off to the nearest 0.1 ppb.
5. Revisions to the simulation output formats. The diurnal output was enhanced so that all dynamic output can now be observed. An EXCEL VBA post processor was created. The output for a dynamic model run is quite large and not easily managed. The postprocessor allows the selection of specific output specified by the user, which can be transferred to an EXCEL spreadsheet for observation and easy plotting.

The model reach structure was set up identical to the 2000 modeling effort. The model has 39 reaches, and 34 point source inputs (figure 4). In the model non-point source tributary inputs are modeled as point sources. There are 15 point source inputs and 19 tributary inputs. The estuary was simulated as a tidally averaged steady state model. Phytoplankton as chlorophyll-a, nutrients as nitrogen and phosphorus, carbonaceous

BOD, periphyton, and dissolved oxygen were simulated as the chemical parameters of interest.

Model Transport

In the hydraulic component of the model, river velocity and depth relationships are developed as a function of flow. Transect and time of travel data are used as a basis for deriving the relationships. QUAL2EU offers two options for the transport of pollutant parameters; a power equation and the Manning equation for open channel flow. The power equation option was chosen for the Penobscot River model. This computes velocity and depth as a function of flow with the following equation:

$$\mathbf{V = A_1 Q^{B}{}_{1} \quad and \quad D = A_2 Q^{B}{}_{2}}$$

where V = velocity; D = depth; Q = flow, and A_x, B_x are coefficients that are empirically derived from transect and time of travel data

The hydraulic coefficients were already calculated from a previous MDEP modeling effort (see Penobscot River Basin Waste Load Allocation, P. Mitnik, 1991). No changes were made to the 1991 model hydraulic coefficients (table 3).

Dispersion or longitudinal spreading becomes very significant in the estuary and must be appropriately considered. A conservative parameter such as the salinity data is generally used to calibrate the dispersion rates to use in the estuary. Initial estimates of dispersion can be obtained by plotting Ln salinity Vs river mile. The dispersion is then the estuary advective or flushing velocity divided by the slope of the Ln salinity Vs river mile. Initial estimates of dispersion rates used in the estuary ranged from 5 to 150 mi^2/day and resulted in a good fit of the salinity data to measured values (figure 4a, 5, table 4).

Flow data is available at a number of locations throughout the Penobscot River watershed. USGS gages that were used include the Penobscot River at West Enfield; Mattawamkeag River at Mattawamkeag; and Piscataquis River at Medford. A flow balance was calculated for the watershed (table 5) using this available flow information and a proration of watershed drainage area for tributary inputs to the Penobscot. The larger tributaries were input to the model as point sources and the smaller tributaries were grouped as incremental flow inputs or distributed loads.

Chemical Calibration of the Water Quality Model

The chemical calibration of the model involves inputting measured tributary and treatment plant effluent as point source loads, measured upstream and downstream boundary conditions and measured water temperature as initial conditions. The model output of various parameters, such as BOD, chlorophyll a, and dissolved oxygen are compared to measured values and adjustments are made to the model parameter rate coefficients until a good match of model and observed data occur. The model parameter rates that are adjusted include many inputs (see Tables 6, 7). Default values are used as initial estimates and adjusted within the ranges recommended in the literature until satisfactory results are achieved. The model is verified after satisfactory results are obtained from a comparison of modeled Vs observed data of a second independent data set. After this process, the model can then be reliably used for model predictions of water quality.

The 1997 data collected on August 3, 4, and 5 were used to calibrate the Penobscot River water quality model. This is discussed in the 2000 modeling report. The 2000 modeling report stated that "*calibration ordinarily involves verification with a second independent data set. A second three-day data set was not collected in 1997 and for this reason the update of the model is considered incomplete. An additional three-day data set is recommended for the next year MDEP is scheduled to be in the Penobscot River watershed, which is the summer of 2001*."

The 2001 data are used in this report to verify the model. The verification effort actually involves re-consideration of parameter rates in both data sets. The lack of a satisfactory calibration for chlorophyll-a on the West Branch locations, in particular, was considered a weakness of the original calibration effort. The addition of the periphyton module and the capability to simulate daily dissolved oxygen fluctuations in QUAL2MDEP should result in better model calibration. Many of the algae component parameters were changed in this modeling effort. The parameter rates used in the model calibration / verification are displayed in tables 6 (rates variable by model reach) and 7 (rates constant in all model reaches). The rates used for the Penobscot River were within ranges recommended in the literature.

The model calibration / verification are plotted for each chemical parameter (figures 8 to 14) in a river mile Vs chemical parameter format. The model output is displayed as a line and the data as an average (unshaded square) and range (high and low error bars). To aid the reader, a column plot (figure 6) shows the river mile of all sampling locations.

Due to the very low level of ammonia measured in the river, BOD was modeled as total ultimate BOD and not partitioned into the carbonaceous and nitrogenous fractions. A benthic CBOD source rate of 30 mg / ft^2-day was assigned to all model reaches. This value was obtained by a trial an error procedure in the modeling that resulted in UBOD values throughout the entire river in the model output that were similar to background values, after all point sources were removed.

In a large river with many impoundments where currents are not significant, the UBOD decay rates derived in the laboratory test often give satisfactory results for an estimation of the actual ambient rates. The Penobscot falls into this category river type. The laboratory rates are derived from a least square regression line fit of many UBOD values measured over the 60 day time period. The following equation is used in this analysis.

$\mathbf{BOD_t = UBOD\ (1\text{-}e\text{-}^{kt})}$ Where BOD_t = BOD in ppm at any given time
UBOD = The final ultimate BOD in ppm
K = The BOD decay rate (/day)
T = Time in days.

Depending upon the data set, the UBOD decay rates varied from 0.03 to 0.05 /day. The 97 data set was assigned a rate of 0.05 /day and the 01 data set 0.04 /day in fresh waters and 0.03 /day in tidal waters. This results in a satisfactory fit of modeled to observed UBOD values (figure 7).

An examination of the data reveals that a large loss of phytoplankton occurs immediately below the Weldon dam impoundment. The majority of the loss is probably due to the die-off of algae. This may be due to the change in river environment from impounded to free flowing waters. The algae in the impoundments are not suited to thrive in the flowing environment and hence the rapid die-off. There is no direct input for an algae die-off rate in QUAL2, but this can be simulated as settling to compensate for this deficiency in the model (Some of the algae loss may actually be settling.)

There appears to be a large uptake of dissolved phosphorus from the Rockabema dam to the Weldon dam in excess of that needed for algae growth. An additional PO4-P uptake rate was assigned to three model reaches (9 to 11) here. Both QUAL2 versions have a direct input for an orthophosphorus source to the water column from the sediment, but not a direct input for uptake, or orthophosphorus loss from the water column to the sediment. Orthophosphorus uptake, this can be indirectly simulated as a negative source rate from the sediment.

When these and some other adjustments were made to the model, a good calibration of chlorophyll-a and nutrients results (figures 7 to 11).

The dissolved oxygen calibration involves both a daily average calibration and a daily minimum calibration. The former involves running the model in the steady state mode and comparing the model output to the daily average dissolved oxygen observed in both data sets. The latter involves running the model in the dynamic mode and comparing the model output to the AM and PM dissolved oxygen observed in both data sets.

In the 2000 modeling effort, periphyton and the resulting diurnal dissolved oxygen swings could not be directly modeled. To simulate the daily minimum dissolved oxygen, a diurnal adjustment was made to the model run in steady state mode. The diurnal adjustment was based the difference observed in the data between the daily average and daily minimum dissolved oxygen (Figure f2, Penobscot River Modeling Report, June 2000). Since periphyton can now be modeled, this diurnal adjustment is no longer necessary except in tidal waters. The difference in river depth and water chemistry in downstream boundary (ocean) when comparing the low and high tide data results in the necessity of a diurnal dissolved oxygen adjustment. Simulation of time variable boundaries and depth is not possible in QUAL2. The diurnal adjustment applied to tidal waters ranged from 0.10 to 0.50 ppm (Figure 12).

The calibration of dissolved oxygen involves the initial steps of calibrating BOD, chlorophyll a, and nutrient and subsequent steps of estimating the reaeration rate (K_a) and sediment oxygen demand rate (SOD) for each modeled reach of river[4]. K_a and SOD are typically very variable over the length of a river and the rates assigned can be quite different reach by reach. The rates assigned to the model are identical to those assigned in the 2000 modeling effort (Table 6).

There are a number of formulas to estimate reaeration based upon research by experts. Up to eight different formulations can be specified by the user in QUAL2. The O-Connor Dobbins reaeration formula which calculates reaeration as a function of velocity and depth was used in most reaches.

$$\mathbf{k_a = 12.85\ V^{.5}/D^{1.5}}$$ where v = velocity in fps, and D = depth in ft

In the deeper and lower velocity reaches, k_a was calculated by an impoundment reaeration formula which is considered a lower bound for k_a whenever the O Connor-Dobbins formula results in a lower estimate.

$$\mathbf{k_a = 3/D}$$

This option is not directly available in QUAL2, but can be calculated outside the model and input as a user specified rate.

SOD analysis at eight river and four estuary locations was undertaken in the autumn of 2001 led by USEPA with field assistance from MDEP and the Penobscot Nation. The data report of May 2002 describes the SOD sample collection as follows: *"In most sample locations of the Penobscot, it was difficult to collect sediment samples in the main channel, due to the lack of adequate sediments. There is, no doubt, great scouring of sediments in a large river such as the Penobscot occurs during high flow periods. Sediment samples were collected in known depositional areas that were often outside the main channel."* The results of the SOD analysis resulted in high levels at many locations when compared to other river systems in Maine. The model inputs were often much lower than those reported in the analysis (Figure 13). It is deduced that the SOD in depositional areas may be much higher than the average value throughout the river bottom. The SOD measured in depositional areas is a good upper boundary of the maximum amount that can be expected on the Penobscot.

The parameter rates used for each model reach are summarized in table 6. The calibration of dissolved oxygen with these parameter rates results in a good fit of the model output to the daily average (Figure 14) and daily minimum of the measured data (Figure 15). Of all sample locations compared, 71% and 87% of average dissolved oxygen were within 0.2 and 0.3 ppm, respectively, of the observed data.

---

[4] The reaeration rate, K_a, is the rate at which oxygen from the atmosphere enters the water column at the surface. K_a is typically high in stretches of rapids or shallow water, and low in impounded or sluggish water. Sediment oxygen demand is the oxygen demand exerted by bottom sediments to the water column.

Model Predictions Runs at 10-Year Low Flow

After the water quality model is calibrated to observed data, a prediction run is made at worst case conditions to assure dissolved oxygen criteria will be achieved at all locations. Worse case conditions are defined by low river flows, when dilution of wastewater is at a minimum; by high water temperatures, when the saturation of dissolved oxygen is lower and BOD decay and oxygen demand from the sediment are higher; and by point sources discharging at licensed limits. Non- point source loads are accounted for as tributary loads with pollution concentrations as measured in the August 1997 survey, distributed load inputs in the model incremental flow, and as sediment oxygen demand (which results partially as sediment that has settled during runoff events prior to low flow).

The 7-day 10-year low flow (7Q10)[5] is used to assess compliance with dissolved oxygen criteria. Prior estimates of 7Q10 were based upon USGS gages at the period of record up to 1991. This analysis was updated to also include the years from 1992 to 2002. The updates resulted in new 7Q10's of 3070 cfs at the West Enfield gage and 3170 cfs at a discontinued USGS gage at Eddington (Figure 16). A flow balance was derived to determine various 7Q10 flows and 1Q10 flows at different locations (Table 5). Dilutions for the toxics program regulation for point source discharges (Chap. 530.5) will be changed based upon this updated information (Table 8).

Table 8 Dilution of Riverine Point Source Discharges

	Effl Flow	River	River	Old Dilution		**New Dilution**	
	mgd	7Q10 cfs	1Q10 cfs	Chronic	Acute	**Chronic**	**Acute**
GNP West	43	2216	2000	30.1	7.5	**33.2**	**7.8**
Millinocket	2.33	2219	2000	556	140	**615**	**139**
GNP East	33	2226	2007	39.2	9.8	**43.5**	**10.1**
Eastern Paper	16.3	2822	2703	111	24.6	**112**	**27**
Lincoln	1.07	2822	2703	1626	349	**1703**	**408**
Old Town	1.7	2795	2521	1191	254	**1062**	**239**
GP Old Town	24.4	2802	2527	83.5	17.7	**74.1**	**17**
Orono	1.84	3178	2867	1329	283	**1115**	**252**
Veazie	.35	3183	2871	12251	2604	**5868**	**1323**
Bangor	18	3206	2892	139	30.2	**116**	**26.2**
Brewer	5.19	3243	2925	478	102	**404**	**91.2**

To determine the appropriate river temperature that should be used for the design in the model prediction runs, historical temperature data was first examined at Eddington. This data appears to indicate a trend of increasing river temperature from 1979 to 1994. It was determined that water temperatures of 25 ^{o}C and 24 ^{o}C were appropriate to use as weekly

[5] The 7-day 10-year low flow (7Q10) is the lowest 7-day average flow expected to occur at a frequency of once in ten years. The 1-day ten year low flow (1Q10) is the lowest single day flow expected to occur at a frequency of once in ten years.

average and monthly averages values, respectively (Figure 17). Since the river temperature can vary by as much as 9 ^oC when comparing all sample locations on any given day, adjustments were derived for other locations based upon the 1997 and 2001 data (Figure 17). Hence the design weekly average river temperature is about 23 ^oC at Millinocket; increases to 25 ^oC in Bangor; and eventual decreases to about 15 ^oC at Bucksport (Figure 17). Note that the water temperatures experienced in the 2001 survey for three consecutive days are considered extreme, and would probably not occur for seven consecutive days simultaneously at a 7Q10 flow event.

Two tests are run with the water quality model to check dissolved oxygen compliance with statutory criteria; one to test compliance of minimum dissolved oxygen criteria and a second to test compliance with the monthly average criteria of 6.5 ppm. In the first test assessing compliance with minimum dissolved oxygen criteria, river flows are inputted as 7Q10; river temperatures are inputted as a weekly average; and point sources are inputted at their weekly average licensed loads. Since the paper mill licenses have no weekly average BOD5 on their permit, ratios of weekly average to daily maximums were derived, based on three years of discharge monitoring data provided by the mill personnel. In the second test assessing compliance with monthly average dissolved oxygen criteria, river flows are inputted as 30Q10; river temperatures are inputted as a monthly average; and point sources are inputted at their monthly average licensed loads.

In both these runs, pollutants that are not included in the license such as nitrogen or phosphorus are ordinarily inputted as measured in the calibration data (August 1997 and 2001). The ultimate point source BOD must be derived from the product of a BODu/BOD5 ratio (which is derived from data) and the licensed BOD5 concentration. Point source inputs to the model and related information is summarized in tables 9 and 10.

The classification of the Penobscot River changes from B to C in the riverine portion and is classified SC in the estuarine portion of the river. Although the classification and dissolved oxygen criteria applied to each classification are discussed earlier in the text, it is repeated here for convenience sake. The following five segments define its classification:

1. From the Ferguson Lake outlet to the Mattawamkeag River – Class C
2. From the Mattawamkeag River to 1 mile above the West Enfield Dam – Class B
3. From 1 mile above the West Enfield Dam to the West Enfield Dam– Class C
4. From the West Enfield Dam to Reed Brook in Hampden – Class B
5. From Reeds Brook to Bucksport – Class SC

The dissolved oxygen criteria is as follows:

Class B	Daily minimum $\geq$ 7.0 ppm and 75% of saturation
Class C	Daily minimum $\geq$ 5.0 ppm and 60% of sat.; monthly average $\geq$ 6.5 ppm
Class SC	Daily minimum > 70% of saturation

The model prediction run of point sources discharging licensed amounts indicates that minimum dissolved oxygen criteria should be met in class C and SC segments. However

about 51 river miles are not expected to meet the minimum class B criteria (figure 18). The following locations are projected not to meet minimum dissolved oxygen criteria:

1. A forty-eight-mile class B segment (RM 61 to 13) from the Mattawamkeag River confluence in Winn to the Milford dam. The lowest dissolved oxygen level predicted is 6.3 ppm, which is within 0.7 ppm of minimum class B criteria
2. A three-mile segment (RM -3 to -6) in tidal waters from the approximate location of the Bangor and Brewer outfall pipe to the Reeds Brook confluence. The lowest dissolved oxygen level predicted here is 6.3 ppm, which is within 0.7 ppm of minimum class B criteria

In addition, algae blooms (chlorophyll a > 8 ug/l) are projected for 11 miles of the river including impoundments from Dolby dam to Weldon dam with chlorophyll a levels as high as 14 ug/l predicted. About 11 addition miles of estuarine waters are projected to have chlorophyll a levels between 8 and 9 ug/l, slightly over the bloom threshold .

The model prediction run at 30 Q10 flow to check compliance with monthly average dissolved oxygen criteria of 6.5 ppm indicates that criteria will be met everywhere except above the Rockabema dam, reaching a low of 6.4 ppm (figures 19). Since this is within 0.1 ppm or measurement error, it can be considered to be marginally complying with the monthly average criteria.

Model prediction runs with point sources at licensed conditions are compared with point sources at zero discharge levels (figure 17) and point sources at actual discharge levels (Figure 19) as indicates by summer discharge monitoring report from 1999 to 2002. It should first be pointed out that the actual discharge levels are typically much less than licensed discharge levels. For example, point sources collectively discharged about 38% of their licensed BOD5 in the summers from 1999 to 2002 (Figure 21).

The model runs indicate that dissolved oxygen criteria are met at zero discharge conditions, although only marginally at the beginning (RM 61) and end (RM –6) of the class B segment. Point sources collectively contribute up to 1.1 ppm of the dissolved oxygen depletion, which are about 56% of the total deficit from saturation. Of the remaining 44%, there may be additional dissolved oxygen depletion attributable to point sources contribution to sediment oxygen demand.

The model runs comparing licensed conditions to actual conditions indicate that the length of non-attainment is similar with actual discharge levels (47 miles) when compared to licensed discharge levels (51 miles). Dissolved oxygen levels should improve by about 0.2 ppm, and the minimum dissolved oxygen of 6.5 ppm would be 0.5 ppm within Class B minimum criteria. The model inputs for actual discharge levels are summarized in Table 11.

Table 11 Model Input for WWTP Performance Run

	Flow mgd	Flow cfs	DM Load	BOD5 ppm	CBu/B5	NBODU ppm	TBODu ppm	TBODu PPD
GNP West	20.9	32.40	8247	47.3	3.25	19	173	30115
Millinocket	0.82	1.27	177	25.9	2.06	72	125	857
GNP East	21.1	32.71	1451	8.2	2.13	6	24	4146
Eastern Pape	10.8	16.74	5070	56.3	2.23	9	135	12117
Lincoln	0.36	0.56	51	17.0	1.46	17	42	126
Old Town	0.89	1.38	403	54.3	1.63	56	144	1073
GP Old Town	15.9	24.65	3576	27.0	4.85	4	135	17874
Orono	0.72	1.12	99	16.5	1.88	4	35	210
Veazie	0.11	0.17	16	17.4	4.21	5	78	72
Bangor	5.88	9.11	907	18.5	2.91	14	68	3326
Brewer	2.48	3.84	232	11.2	2.2	2	27	552
IP Bucksport	12.9	20.00	1019	9.5	3.63	3	37	4022

Sensitivity Analysis

In a sensitivity analysis, some of the parameter rates can be tested to determine which are more important in the development of the model. The model prediction run at 7Q10 was used as a basis for the sensitivity analysis runs. Four different parameter inputs are tested; the sediment oxygen demand rate, reaeration rate, BOD decay rate, and algae (phytoplankton and periphyton) growth rates. Each parameter was multiplied by a factor of 0.5 and 2 and the model output for dissolved oxygen was then compared as a range at three strategic locations (figure 22). The three locations chosen are above the Rockabema dam, a point midway between the Greenbush and Passadumkeag sampling locations, and at Orrington at the end of the class B segment. It is at these locations that the lowest dissolved oxygen readings are predicted and hence the most sensitivity is expected.

From this analysis it appears that the order of sensitivity in the calibration of the model dissolved oxygen are the atmospheric reaeration rate, followed by the sediment oxygen demand rate, the BOD decay rate, and finally the algae growth rate. The reaeration rate and sediment oxygen demand rate appears to be sensitive at all locations. The algae growth rate appears to be more sensitive in shallower flowing segments (Greenbush-Passadumkeag). The BOD decay rate appears to be more sensitive in the deeper reaches (Rockabema dam and Orrington).

Component Analysis

Components of potential river dissolved oxygen depletion are compared in two ways. First pollutant loads inputs to the Penobscot River as a whole can be computed and compared in pie chart diagrams. The larger loads have more potential for impact.

Second, the actual impact each load has to the river dissolved oxygen depletion can be determined with model prediction runs. In this analysis, load inputs are individually subtracted from the model and the difference in dissolved oxygen predicted by the model from a base case is then observed. The model prediction run at 7Q10 flow and licensed point source loads was used as a base case for the component analysis.

Point source, tributary, and background input loads are compared as pie chart diagrams for total ultimate BOD and total phosphorus (figure 23). The tributary and background loads are computed using pollutant concentrations as measured during the intensive surveys and represent both natural and non-point source pollutant loads. From this analysis it can be observed that point source inputs when discharging at maximum licensed conditions are overwhelmingly the largest source of pollution representing about 74% and 94% of the total input of BOD and phosphorus, respectively.

Point source input loads are compared for BOD5 (Figure 24) and total phosphorus (Figure 25). From this analysis, it can be observed that paper mills collectively are the largest pollutant source that accounts for more than 80% and 70% of the BOD5 and total phosphorus, respectively of all point source discharges. The city of Bangor accounts for about 11% and 18% of the total BOD5 and phosphorus, respectively. Other municipal sources (Millinocket, Lincoln, Old Town, Orono, Veazie, and Brewer) individually seem insignificant, since each discharges is typically less than 3% of the total point source loads. However, when considered collectively, they are significant representing about 8% and 10% of the total point source inputs for BOD and phosphorus, respectively.

The component analysis of the dissolved oxygen deficit is analyzed at the same three strategic locations as the sensitivity analysis; above the Rockabema dam, Passadumkeag – Greenbush midpoint, and Orrington at end of class B segment. Five components of dissolved oxygen depletion were investigated

1. Sediment oxygen Demand (SOD) – Includes all SOD collectively from natural, point source, and non-point sources.
2. Point Source BOD – Includes nitrogenous and carbonaceous BOD from all industrial and municipal sources.
3. Non-point Source BOD - Includes nitrogenous and carbonaceous BOD from tributary and incremental drainage. Includes both natural and non-point source pollution.
4. Background – Model run with no background impact. Dissolved oxygen is adjusted to 100% saturation and background BOD is adjusted to zero. Collectively includes impacts from the initial DO deficit and background BOD from natural and non-point sources.
5. Point Source Nutrients – Diurnal dissolved oxygen impacts from attached and floating algae. Includes nutrient impacts from point sources.

Above the Rockabema dam (Figure 26), sediment oxygen demand and background conditions are the largest factors contributing to dissolved oxygen depletion resulting in about 37% each of the total dissolved oxygen deficit. Point source BOD is responsible for about 18% of the total dissolved oxygen depletion. Point source nutrients and non-point source BOD are less important, contributing about 7% and 1%, respectively to the total dissolved oxygen deficit. At the Passadumkeag – Greenbush midpoint (Figure 26), point source nutrients and sediment oxygen demand are the largest factors contributing to dissolved oxygen depletion resulting in about 45% and 35% of the total dissolved oxygen deficit, respectively. Point source BOD contributes about 11%; background conditions about 5%; and non-point BOD about 4% of the total dissolved oxygen deficit.

At Orrington (Figure 26), point source BOD and sediment oxygen demand and are the largest factors contributing to dissolved oxygen depletion resulting in about 43% and 37% of the total dissolved oxygen deficit, respectively. Non-point source BOD and background conditions are responsible for about 13% and 7%, respectively, of the total dissolved oxygen deficit. Nutrients are unimportant resulting in less than 1% of the total dissolved oxygen depletion.

Investigation of Pollutant Abatement

Model prediction runs with point sources at both licensed and actual conditions resulted in widespread non-attainment (up to ½ of the 103 river miles investigated) of minimum class B dissolved oxygen criteria. In addition, the model predicts that algae blooms should occur in up to ¼ of the length of the 103 miles investigated. Point sources are the main cause of the dissolved oxygen depletion and the algae blooms. Clearly reductions of point source inputs are necessary for attaining compliance of dissolved oxygen criteria.

Additional model runs are made with point source reductions of BOD and phosphorus. Phosphorus is the limiting nutrient responsible for the growth of benthic algae and phytoplankton (floating algae). Limiting phosphorus inputs to the river will limit algae production, which will also alleviate the early morning low dissolved oxygen readings that result from extended evening respiration. The algae typically produce excess oxygen when exposed to light during the daytime through photosynthesis, and the maximum daily dissolved oxygen is reached at mid to late afternoon. Conversely, at night in the absence of light, extended respiration results in a continuing depletion of dissolved oxygen until minimum daily values are achieved at dawn.

The point source reductions can be accomplished in a number of methods. One method could be requiring the larger point sources to undertake most of the reductions, since they are responsible for most of the impact. Another method could be requiring all point source inputs to do some abatement with the larger inputs doing more abatement than the smaller inputs. **In summary, it has been determined that if point source discharges are reduced to levels slightly higher than actual BOD input levels[6] (about a 60% collective reduction from licensed amounts), and point source total phosphorus reduced by about 40% from actual levels, all criteria could be marginally attained.**

[6] For model runs at performance or actual levels, the average of the daily maximum pollutant load inputs for each summer month from 1999 to 2002 were used to simulate weekly average loads at 7Q10 flow (no weekly average load input data was available). The daily maximum load set for point sources would be slightly higher than the inputs used in the model which are a weekly average.

A summary of model run inputs and prediction results (table 12) and point source load inputs for each model run (table 13) illustrate the expected water quality for the various load reductions investigated. Model runs are also plotted in a river mile Vs dissolved oxygen level format (Figure 27). Phosphorus for point source discharges is typically regulated as a monthly average discharge in the summer months (May 15 to Sept 30). BOD5 is regulated in the summer months as a monthly and weekly average or possibly a daily maximum.

Table 13 Summary of Point Source Loads (PPD) in Model Prediction Runs at 7Q10 Flow

	Pen.7qt		PenP.7qt		PenP2.7qt		PenP3.7qt		PenP4.7qt		PenP6.7qt	
	TP	BOD5 WA*	TP	BOD5 DM**	TP	BOD5	TP	BOD5	TP	BOD5	TP	BOD5
GNP West	502	13680	244	8247	87	8247	87	8247	87	8247	87	8715
Millinocket	80	874	28	177	28	177	80	874	28	874	28	205
GNP East	385	6710	246	1451	88	1451	88	1451	88	1451	88	1760
Eastern Pap	114	8191	76	5070	45	5070	45	5070	45	5070	45	2702
Lincoln	35	402	12	51	12	51	35	402	12	402	12	90
Old Town	69	638	36	403	36	403	69	638	36	638	36	223
GP Old Towr	244	12780	159	3576	66	3576	66	3576	66	3576	66	3978
Orono	47	690	18	99	18	99	47	690	18	690	18	180
Veazie	11	131	3	16	3	16	11	131	3	131	3	28
Bangor	650	6755	212	907	212	907	650	6755	212	907	212	1471
Brewer	31	1947	15	232	15	232	31	1947	15	1947	15	620
Totals	**2168**	**52799**	**1050**	**20229**	**611**	**20229**	**1209**	**29781**	**611**	**23933**	**611**	**19973**

* Weekly Average Loads. For paper mills, derived by daily maximum load times WA/DM ratio from discharge monitoring reports.

** Daily maximum load used for performance runs.

It should first be mentioned that the discharges in Winterport and Bucksport are well below the impacted river and estuary segments. Even though some portion of their effluent discharge may reach the impacted segments during an incoming (flood) tide, model runs assessing their impact determined that their inputs collectively is negligible. Hence no point source controls other than those that currently exist within licenses are recommended for Bucksport, Winterport, and the International Paper mill in Bucksport. The dilution and dispersion of the Penobscot estuary in the location of the outfalls of these discharges is very large and adds insurance that regulation of these discharges will do little to improve the non-attainment areas. Also, the estuary becomes nitrogen limited rather than phosphorus limited in Winterport and Bucksport. If nutrient controls were implemented here, nitrogen reductions, rather than phosphorus reductions would be implemented.

It would appear that the most equitable way of achieving the phosphorus reductions would be restricting paper mill discharges to mass loads calculated by actual flow and phosphorus treated to a 0.5 ppm level. Municipal discharges should be capped at current phosphorus input levels based upon actual flow and phosphorus as measured in the 97 and 01 surveys. The required monthly average phosphorus loads for each discharge under this case are summarized in Table 13, run PenP6.7qt (2^{nd} column from far right).

No phosphorus requirements were also investigated for municipal point sources (model run PenP3.7qt) along with the mentioned paper mill reductions, but it was determine that this would not be enough, since 26 river miles would still not attain dissolved oxygen criteria and 10 river miles still experience algae blooms. Additional phosphorus reductions from mill discharges would be necessary without regulating municipal discharges. A 0.5 ppm TP level may be achievable at each paper mill by undertaking process controls, i.e. optimizing phosphorus addition, and levels lower than 0.5 ppm could require large capital investments.[7]

For the BOD reductions many methods are possible. One possible method is holding all point source discharges to performance based standards (model run PenP2.7qt). This may not be the most equitable method, since discharges who are performing well will be regulated at much lower levels than discharges who are performing poorly (hence good operation of a plant is penalized). Another method that appears to be more equitable is requiring BOD5 loads based upon an equal concentration and actual treatment plant flow. A BOD5 concentration of 30 ppm would be required as a weekly average to meet the necessary load reductions. The loads for this method for each point source are summarized in table 13, model run PenP6.7qt (in the column to the far right).

For the phosphorus reductions, two allocation methods are presented for municipal discharges. The first involves capping all municipal discharges at their current mass load. A more equitable method analogous to the BOD allocation method may be calculating required TP loads based upon an equal concentration. The concentration that would be required at actual flow using this method is 3.45 ppm.

Actual treatment plant BOD5 performance data for the years 1999 – 2002 are plotted and compared to current licensed levels and allocation based upon the 30 ppm BOD5 allocation (Figuere 28a, 28b, 28c). Note that the daily maximum allocation is adjusted to reflect a daily maximum rather than the weekly average inferred in the model run. The ratio used for this adjustment are the inverse of those appearing in table 9 (weekly/daily maximum BOD ratio). It appears that Eastern Paper and Old Town would have the most difficulty meeting this allocation. Old Town is currently undertaking a plant upgrade, which could result in significant improvements in performance.

Another possibility, which should be mentioned, is a water quality trading system. Hence a discharge that could have difficulty meeting a required phosphorus or BOD level could possibly trade pollutant credits with another discharge who is expected to be well under future requirements. Note that in the model runs provided, GNP west and GNP east have

[7] Paper mill effluent is typically nutrient deficient and phosphorus is added to the treatment process to optimize BOD removal. Often much more phosphorus is added than what is needed (see GNP study appendix). Studies should be undertaken at each paper mill to determine the minimum amount of phosphorus that needs to be added while still insuring good BOD removal. In some paper mills, studies have determined that no nutrient addition is actually needed.

already been modeled assuming pollutant trading that is more consistent with how the plants actually perform (West is based upon BOD5 = 50 ppm; East BOD5 = 10 ppm). Note that in a pollutant trading system, pollutants are not necessarily traded in a 1:1 ratio, since where each input is located in relation to impacted river areas must also be considered. Finally it should be stated that DEP is open to other allocation methods, so long as the desired goal of attainment of water quality standards is achieved. The following allocations are offered for starting points of discussion.

Table 14 Point Source BOD5 and Phosphorus Allocation
Municipal Discharges

Point Source Discharge	Weekly Average / Daily Maximum BOD5 (PPD)		Total Phosphorus (PPD)	
	Allocate by current discharge	Allocate by equal concentration	Allocate by current discharge	Allocate by equal concentration
Millinocket	180 / 200	210 / 230	28	24
Lincoln	50 / 55	90 / 100	12	10
Old Town	400 / 480	220 / 250	36	26
Orono	100 / 110	180 / 200	18	21
Veazie	16 / 18	28 / 31	3	3
Bangor	900 / 1000	1470 / 1630	212	169
Brewer	230 / 250	620 / 690	15	71
Winterport	Primary Plant		No Restriction	
Bucksport	Primary Plant		No Restriction	

Paper Mills

Point Source Discharge	Weekly Average / Daily Maximum BOD5 (PPD)		Total Phosphorus (PPD)	
	Allocate by current discharge	Allocate by equal concentration	Allocate by equal % Reduction	Allocate by equal concentration
GNP West	8200 / 10800	8700 / 11500	96	87
GNP East	1450 / 2600	1800 / 3200	97	88
E Paper Lincoln	5000 / 6800	2700 / 3700	30	45
G Pacif Old Town	3600 / 5100	4000 / 5600	63	66
IPCo Bucksport	7100 / 10000*	No Restriction		

* Current licensed levels

Responses to Comments